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STO TECHNICAL REPORT

TR-SET-144

Mitigation of Ship Electro-Optical Susceptibility Against Conventional and Asymmetric Threats

(Atténuation de la vulnérabilité électro-optique des navires contre les menaces conventionnelles et asymétriques)

Final Report of Task Group SET-144/RTG-79.

Published April 2014

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Final Report of Task Group SET-144/RTG-79.

The NATO Science and Technology Organization

Science & Technology (S&T) in the NATO context is defined as the selective and rigorous generation and application of state-of-the-art, validated knowledge for defence and security purposes. S&T activities embrace scientific research, technology development, transition, application and field-testing, experimentation and a range of related scientific activities that include systems engineering, operational research and analysis, synthesis, integration and validation of knowledge derived through the scientific method.

In NATO, S&T is addressed using different business models, namely a collaborative business model where NATO provides a forum where NATO Nations and partner Nations elect to use their national resources to define, conduct and promote cooperative research and information exchange, and secondly an in-house delivery business model where S&T activities are conducted in a NATO dedicated executive body, having its own personnel, capabilities and infrastructure.

The mission of the NATO Science & Technology Organization (STO) is to help position the Nations' and NATO's S&T investments as a strategic enabler of the knowledge and technology advantage for the defence and security posture of NATO Nations and partner Nations, by conducting and promoting S&T activities that augment and leverage the capabilities and programmes of the Alliance, of the NATO Nations and the partner Nations, in support of NATO's objectives, and contributing to NATO's ability to enable and influence security and defence related capability development and threat mitigation in NATO Nations and partner Nations, in accordance with NATO policies.

The total spectrum of this collaborative effort is addressed by six Technical Panels who manage a wide range of scientific research activities, a Group specialising in modelling and simulation, plus a Committee dedicated to supporting the information management needs of the organization.

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These Panels and Group are the power-house of the collaborative model and are made up of national representatives as well as recognised world-class scientists, engineers and information specialists. In addition to providing critical technical oversight, they also provide a communication link to military users and other NATO bodies.

The scientific and technological work is carried out by Technical Teams, created under one or more of these eight bodies, for specific research activities which have a defined duration. These research activities can take a variety of forms, including Task Groups, Workshops, Symposia, Specialists' Meetings, Lecture Series and Technical Courses.

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Table of Contents

List of Figures/Tables

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Mitigation of Ship Electro-Optical Susceptibility Against Conventional and Asymmetric Threats

(STO-TR-SET-144)

Executive Summary

As stated in the SET-144 Terms of Reference, the main research areas of the Task Group were:

- Infrared (IR) modeling of military ships;
- Ship-borne Infrared Search and Track systems (IRST) and their detection of point targets;
- IR signature/detectability of small craft;
- Evaluation of IR ship signature monitoring and management systems; and
- Infrared modeling challenges unique to the littoral environment.

In the execution of this research, the Task Group maintained close liaison with several other NATO entities:

- SET-154 "Signature Management System for Radar and Infra-Red Signatures of Surface Ships";
- SET-134 "Radar and IR Synergy for Military Situation Awareness"; and
- MCG-8 "Maritime Capability Group 8 on Maritime Electronic Warfare".

SET-144 advanced the state-of-the-art and knowledge-base in all areas of research in the TOR. The major/tangible accomplishment was the planning, execution and analysis of the SQUIRREL trial.

Radiometric IR measurements were made on many types of targets:

- A 77 m research ship;
- Small marine targets (a RHIB, speedboat and combat swimmer);
- IR ship decoys; and
- A pair of small calibrated sources that simulated the signature of an anti-ship cruise missile.

The unique aspect of this experiment is it tested the effectiveness of an IR ship signature reduction system. The results of the trial were conclusive that the signature management system not only reduced signature, but would reduce missile acquisition range and improve the seduction effectiveness of off-board decoys. All of the participating countries combined their results into a comprehensive database, which is available to benefit NATO navies. The resources required to conduct such a state-of-the-art trial (ship modifications, ship transit from Canada to Germany, ~3.5 man-years of effort, 100 decoys, helicopter flight-hours) ~ € 950 k, which is too expensive for any one country to manage on its own. Clearly, close NATO cooperation is essential.

Atténuation de la vulnérabilité électro-optique des navires contre les menaces conventionnelles et asymétriques

(STO-TR-SET-144)

Synthèse

Comme indiqué dans les mandats du SET-144, les principaux domaines de recherche du groupe de travail portaient sur :

- La modélisation infrarouge (IR) de navires militaires ;
- Les systèmes embarqués de veille et poursuite par infrarouge (IRST) et leur détection d'objectifs ponctuels ;
- La signature et la détectabilité IR de petits navires ;
- L'évaluation des systèmes de surveillance et de gestion de la signature IR des navires ; et
- Les problèmes spécifiques de la modélisation infrarouge dans les environnements littoraux.

Le groupe de travail a gardé un contact étroit avec plusieurs autres entités de l'OTAN lors de la réalisation de cette recherche :

- Le SET-154 « Système de gestion de signatures pour les signatures radar et infrarouge des navires de surface » ;
- Le SET-134 « Synergie radar et IR pour l'appréciation de la situation militaire » ; et
- Le MCG-8 « Groupe Maritime Capacitaire 8 Relatif à la Guerre Electronique maritime ».

Le SET-144 a permis de faire avancer la connaissance et l'état de l'art dans tous les domaines de son mandat de travail. La réussite la plus importante / la plus tangible a été la planification, l'exécution et l'analyse de l'essai SQUIRREL.

Des mesures IR radiométriques ont été réalisées sur plusieurs type d'objectifs :

- Un navire de recherche de 77 m ;
- Des petites cibles marines (une RHIB, un canot à moteur et un nageur de combat) ;
- Des leurres IR de navires ; et
- Une paire de petites sources conçues pour simuler la signature d'un missile de croisière antinavire.

Le caractère unique de cette expérience reposait dans les essais d'efficacité d'un système de réduction de la signature IR des navires. Les résultats de cet essai ont conclu que le système de gestion de signature réduisait non seulement la signature, mais réduirait également la portée d'acquisition d'objectif des missiles et améliorerait l'efficacité de la déception par des éjections de leurres hors bord. Tous les pays participants ont partagé leurs résultats pour établir une base de données exhaustive, qui est disponible au bénéfice des marines militaires de l'OTAN. Les ressources nécessaires à la mise en œuvre d'un tel essai, ~950k € (modifications de navires, transite des navires du Canada à l'Allemagne, ~3,5 années-personne, 100 leurres, heures de vol en hélicoptère), sont trop élevées pour qu'un seul pays s'attèle à cette tâche. Il est manifeste qu'une coopération étroite de l'OTAN est essentielle.

Mitigation of Ship Electro-Optical Susceptibility Against Conventional and Asymmetric Threats

1.0 INTRODUCTION

As stated in the SET-144 Terms of Reference, the main research areas of the Task Group were:

- Infrared (IR) modeling of military ships;
- Shipborne Infrared Search and Track (IRST) systems and their detection of point targets;
- IR signature/detectability of small craft;
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In the execution of this research, the Task Group maintained close liaison with several other NATO entities:

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- SET-134 "Radar and IR Synergy for Military Situation Awareness"; and
- MCG-8 "Maritime Capability Group 8 on Maritime Electronic Warfare".

SET-144 was approved to operate and exchange information up to and including NATO SECRET although most of the work was carried out at the Unclassified or NATO CONFIDENTIAL level.

2.0 MEETING SUMMARY

SET-144 was active from January 2009 to December 2012**.** Over this time period, the Task Group held seven (7) meetings and executed one major field campaign. The meetings are summarized in Table 1, and the field campaign is described in detail in Section 5.0 of this report.

Table 1: Meeting Summary.

Date	Location
31/03/09	NLD, TNO: The Hague
06/10/09	CAN, DRDC: Val Bélair, Québec
12/04/10	DEU, WTD-71, Eckernforde
29/09/10	GBR, Dstl: Portsdown West
12/04/11	CAN, DRDC: Halifax, Nova Scotia
16/04/12	NOR, FFI: Oslo
16/10/12	BEL, RMA: Brussels

3.0 SHIP SIGNATURE RESEARCH

Research on infrared ship signatures was a major area of collaboration for SET-144. This was a significant portion of the "Country Reports" presented by member countries at each meeting. Most of the member countries planned and executed national trials on IR ship signatures. When these national trials occurred, each country shared as much of the technical results as possible (within security constraints) and also provided lessons-learned with respect to test execution, measurement results, signature modelling techniques, and individual county work on model validation.

Most of the member countries use the same IR signature model, ShipIR. This proved to be an efficient mechanism for scientific data exchange. Some countries use their own country-developed model and some use both types. This provided an opportunity for cross-validation of models. This work was particularly fruitful, since different models have different strengths and weaknesses. Through comparisons to field data, the Task Group was able to discern which models were better at predicting different phenomenology. This validation mechanism hastened the improvement of all models involved.

4.0 ATMOSPHERIC PROPAGATION RESEARCH

The major activities for IR propagation research involved building upon previous NATO propagation trials, VAMPIRA and SAPPHIRE. The new trial executed by SET-144 was designed specifically to address "gaps" from those previous trials.

Probably the key lesson-learned from the VAMPIRA and SAPPHIRE is the importance of making multiple meteorological measurements to include duplicate measurements at the same location and measurements at many varied locations throughout the operations area. The more-comprehensive meteorological data set significantly improves the validation of the models by enabling the distinction between true errors in the model and errors resulting from incomplete or wrong input data. This historical shortcoming was successfully mitigated in the SET-144 SQUIRREL trial.

5.0 TEST CAMPAIGN

5.1 Introduction and Background

Several multi-national trials have been conducted in the past [1]. Propagation data from these trials have been used to understand the phenomenology and validate predictive models, such as the IR Boundary Layer Effects Model, IRBLEM [2]. While these trials have provided valuable information, ultimately they were limited by the accuracy and coverage of the ground-truth or local meteorological measurements. Previous NATO ship signature trials have focused on measuring signatures of typical ship targets and validating predictive signature models [3].

The NATO SQUIRREL trial was planned to address shortcomings from previous trials and expand the scope of information obtained. It was conducted at the German Naval Test range in Surendorf, Germany on the Baltic Sea from 11-23 September, 2011. Infrared test teams from 10 different NATO countries participated (Australia, Belgium, Canada, Germany, Greece, Italy, Netherlands, Norway, UK and US).

The **major objective** of this trial, as stated in the Trial Plan, was to test the IR signature susceptibility properties of a Canadian research ship (CFAV Quest) with an IR Ship Signature Management System (SMS), specifically:

- Hull signature;
- Plume signature; and
- Full ship susceptibility/effectiveness of signature reduction measures with regard to IR seekers with/without off-board countermeasures (i.e. decoys).

Additional objectives of the SET 144-Trial at Surendorf included:

- Propagations measurements (MWIR/VIS); and
- Small target detection.

In order to accomplish these objectives, three different types of tests were performed:

- IR ship signature measurements of the CFAV Quest:
    - With and without SMS operating; and
    - Decoy deployment with and without SMS operating.
- IR detection of small craft and simulated point source targets.
- Long-path turbulence and scintillation experiments and their effect on long range detection at-sea.

In addition to the continuous atmospheric runs, a total of 83 runs were executed over a two-week period. Extensive ground truth was measured as well. Multiple meteorological (met) stations measured weather conditions over the entire operating area including pier side met stations, met buoys and ship-borne met stations. Additionally, Global Positioning Systems (GPS) provided reliable and accurate time-space-position information.

The data from this trial has been reduced and analyzed. A summary of the data from the various types of runs will be presented.

5.2 Test Ship with Signature Management System (SMS)

An infrared Onboard Signature Manager (OSM) system is made by Davis Engineering, Ottawa, Canada, and was installed on the Canadian research ship, CFAV QUEST, Figure 1.

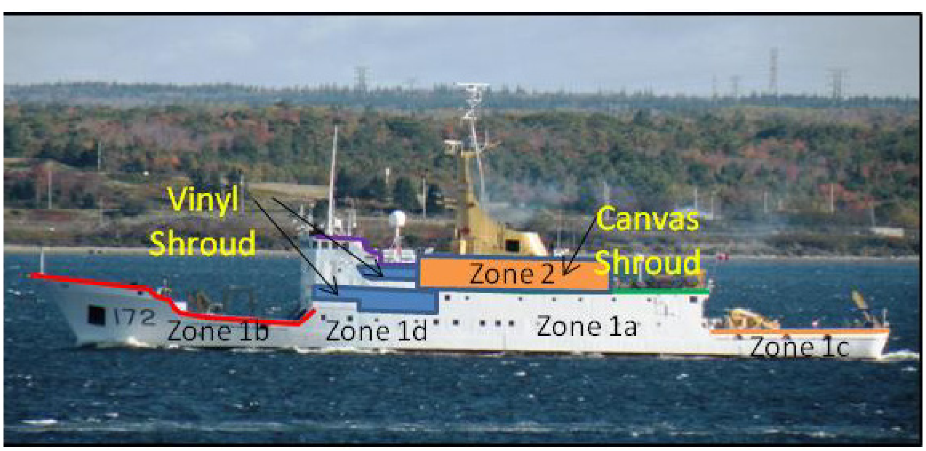


Figure 1: Canadian Research Ship CFAV Quests with SMS System.

The OSM system is comprised of two major sub-systems: Sea Water Injection (SWI) and Automated Hull Cooling (AHC).

5.2.1 Sea Water Injection (SWI)

The Davis SWI plume cooling system is used to achieve a reduction in exhaust gas temperature for ship exhaust systems. The device can be specified to cool the gas to below 150 degrees C. The SWI plume cooling system reduces plume temperature by injecting a fine water mist directly into the exhaust stream.

The SWI system relies on the evaporation of atomized water droplets in the exhaust to absorb thermal energy from the exhaust gas. The droplets are injected into the exhaust stream with a spray system, which consists of an array of nozzles. These spray nozzles are supplied with sea water by either the fire-fighting pumps or a separate pumping system. The flow of the water is monitored and regulated by a control unit (the OSM) which interfaces to the ship Integrated Machinery Control System (IMCS).

The SWI system is comprised of a water injection assembly followed by a length of duct over which the water droplets evaporate.

5.2.2 Automated Hull Cooling (AHC)

The AHC system automatically controls the temperature of the ship skin in order to minimize the susceptibility of the ship to IR-guided missiles. The AHC system augments the Nuclear Biological Chemical (NBC) water-wash system by providing full wash-down of the ship structure.

The AHC system is comprised of the following main components:

- Hull temperature sensors;
- Ambient environment sensors;
- Water flow control valves, actuators, and sensors;
- Four types of water sprinklers, including the custom designed Davis fan nozzle;
- Nozzle for spraying hull surfaces; and
- The OSM.

5.2.3 IR Onboard Signature Manager (OSM)

The AHC and SWI systems are controlled by the OSM computer. The OSM is built upon the US and NATO standard IR signature prediction code ShipIR/NTCS. Using real-time measurements of the ship skin temperature, ambient environmental conditions, and ship operating state, the OSM is able to determine the optimal state of the SWI and AHC systems to minimize susceptibility to IR guided missiles. The OSM can be software upgraded to predict the ship’s contrast IR signature in real time, providing important situational awareness for the combat officer.

5.3 Participants and Location

The trial was conducted at the German WTD-71 Surendorf test range near Eckernförde Navy Base, Figure 2. The participating countries set up their infrared instrumentation either on the end of the pier or on the top two floors of a building overlooking the test site, indicated by the yellow oval in Figure 3.

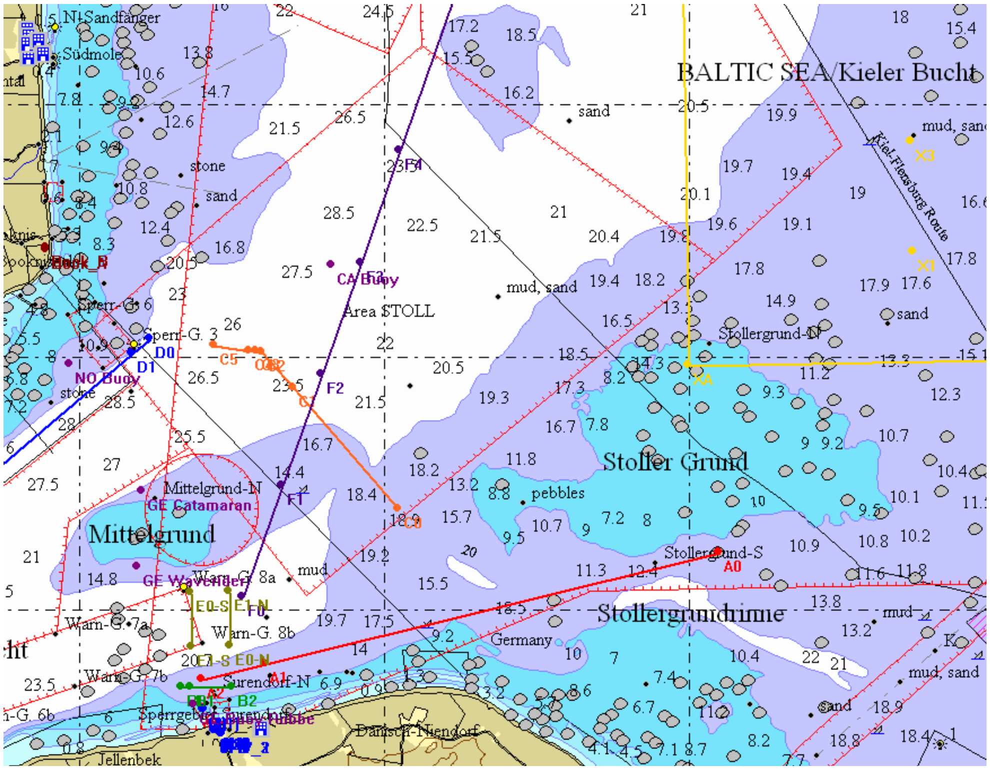


Figure 2: Trial Area Near Baltic Sea, Germany.

Figure 3: Shore Site Near Surendorf.

5.4 Trial Overview

An overview of the run types is shown in the table below.

Table 2: Run Overview.

Run Type	Ship Track	Ship Configuration
Short Range – Ship	A	OSM On/Off
Short Range – Plume	B	Stbd Diesel only 75% and 100%
Short Range – Decoy	E	2 Diesels, 10 kts
Long Range	C	OSM On/Off, Decoy or Not
Littoral Background	D	2 Diesels, 10 kts
Mittlegrund Track	F	10 kts
Small Boats / Swimmer	F	In-bound and Out-bound

The Short-Range Ship and Plume runs, Tracks A and B, were meant for a close range radiometric signature characterization of the AHC and SWI systems. The Short-Range Decoy runs, Track E, are for detailed radiometric measurements of the ROSY (Rapidly Obscuring System) IR decoy, described below. Littoral runs, Track D, are meant to collect long-range IR imagery of the ship against a coastal background. Track F is an "in-bound/out-bound" track used for detection range studies of several targets: IR sources on the Mittlegrund range support ship, small craft, and combat swimmers (provided by the German test facility).

The primary run type was the Long Range, Track C. The objective of this type of run was to collect long-range IR radiometric imagery of the test ship launching IR decoys, both with and without the OSM system turned on.

The Rheinmetall ROSY decoy was fired during this trial. The launchers were installed on the Quest at a nearby German Naval base, WTD-71, just prior to the IR trial. This decoy was designed for smaller ships than the Quest (e.g. coast guard cutters and patrol boats) so it was expected to not be an effective decoy under standard ship signature levels. The trial was designed to test the hypothesis that the decoy would be more effective with the OSM system turned on.

5.5 Summary of Results

A summary of the various types of runs is shown in Table 3.

Table 3: Number of Runs Executed by Run Type.

Run Type	Number of Runs Executed
Short Range – Ship	7
Short Range – Plume	16
Short Range – Decoy	12
Long Range	34
Littoral Background	5
Mittlegrund Track	9
Small Boats / Swimmer	11 (5 RHIB, 3 AM-7, 3 Swimmer)

5.5.1 Short Range – Ship

The purpose of the Short-Range Ship runs was to collect very high spatial resolution IR data on the Quest during a "normal" signature condition, i.e. with the OSM system off and a reduced signature condition with the OSM system turned on. A typical measurement range was ~1000 m. An example of this type of imagery is shown in Figure 4.

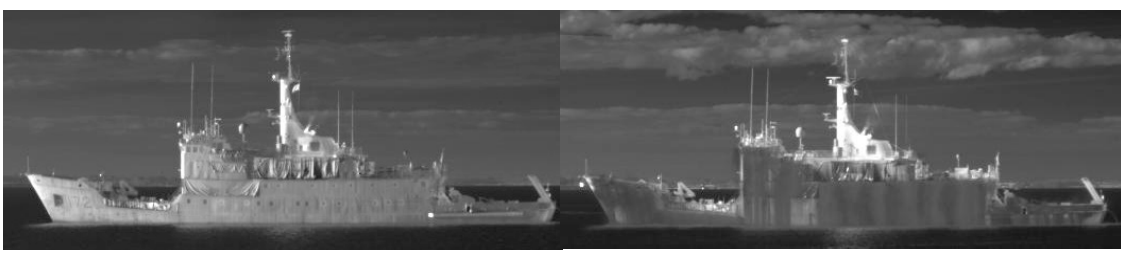


Figure 4: IR Images of Quest with SMS Off (left) and On (right).

An examination of Figure 4 shows that the mast is not treated; however, the remainder of the ship shows good coverage of the AHC system. If obvious problems were observed during these preliminary runs, mitigating action would have been taken before the long-range decoy runs were executed. The conclusion from this run type was that the combined OSM system was working at nominal performance.

5.5.2 Short Range – Plume

For this type of run, the objective was to collect diesel plume signature data at the shortest range that the local water depths allowed, which was approximately 500 m. Most participating countries collected IR imagery during this run; the Norwegian team collected MWIR spectral data with their FTIR spectrometer. A typical IR image of the plume without the SWI activated is shown in Figure 5.

Figure 5: Short-Range IR Image of the Starboard Diesel Plume.

5.5.3 Short Range – Decoy

As with the short-range ship runs, the objective of this run type is for detailed signature measurements, which will aid in the understanding of the primary long-range ship and decoy runs. Since ROSY is a wind-blown decoy, it could only be fired under certain wind conditions. Approximately six runs were executed and were at a range of about 1500 m. An example IR image is shown in Figure 6.

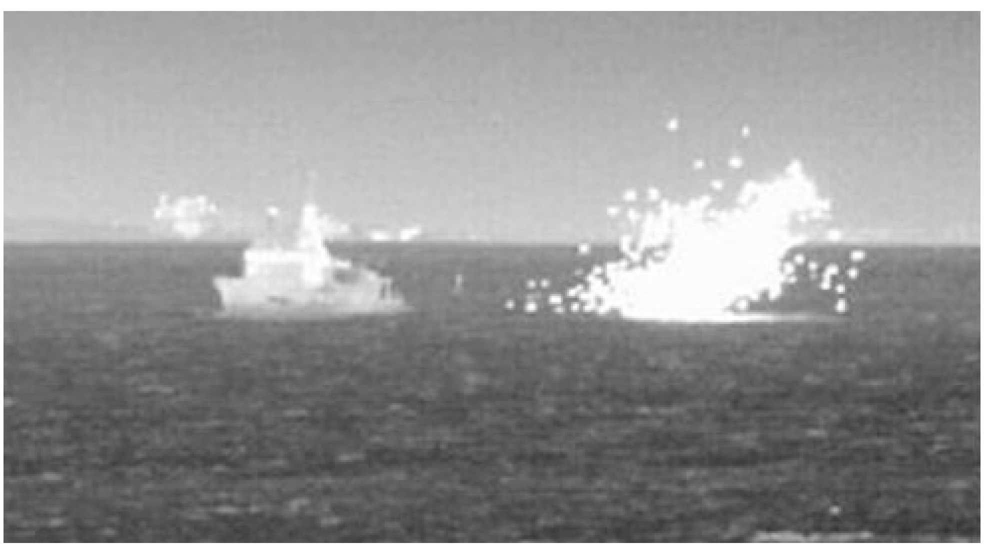
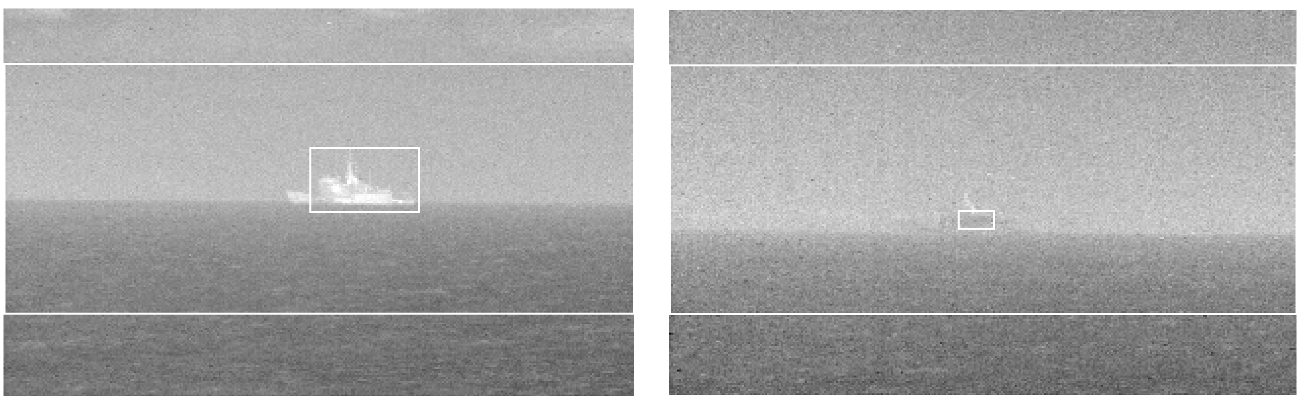


Figure 6: Short-Range IR Image of the ROSY Decoy.

5.5.4 Long Range

As previously stated, the Long-Range runs were the primary objective of the trial; most of the short-range runs were to obtain radiometric signature of the key elements (ship, plume, and decoy) to enable analysis of these Long-Range runs. The range at decoy deployment was about 4500 m. Approximately 100 decoys were deployed over the trial. All runs were executed in pairs: OSM off then OSM on. This dynamic IR imagery would later be played back into open-loop anti-ship seeker simulations to assess if the decoy was more effective with the OSM system on. Most of the runs only used one sub-munition to simplify the post-test seeker analysis; re-acquisition was not tested so re-seeding the decoy was not necessary. However, later in the trial the US test director expanded the scope of the trial with multiple sub-munition experiments. Decoy deployment tactics (launch azimuth) were decided in real time on a run-pair basis using tactical decision aid software operated in the Test Control room.

The Dutch team from TNO, played back imagery for both OSM-off and OSM-on cases into their generic imaging IR anti-ship seeker tracking algorithm. They reported that the decoys were more likely to cause a tracker break-lock if the OSM system was turned on [4]. Screen-captures for the on/off cases used by TNO are shown in Figure 7.



(a) (b)

Figure 7: Long-Range Images with OSM Off (a) and On (b).

5.5.5 Littoral Background

Five runs were executed with the Quest at long range with a littoral background; see Track "D", indicated in blue on Figure 2. Several countries were interested in this run to assess how a land background behind the ship affects susceptibility to automatic target detection and recognition algorithms.

5.5.6 Small Boats / Swimmer

Detection trials on various maritime targets were also executed on Track F. There were three types of small targets:

- A rigid hull inflatable boat (RHIB);
- A small speed boat (called AM-7); and
- A combat swimmer based out of the WTD-71 Naval Base across the bay.

The swimmer only swam short distances along Track F. Both the swimmer (middle-left) and RHIB (upper-right) are shown in an IR image in Figure 8.

Figure 8: IR Images of Swimmer (lower-left) and RHIB (upper-right)

5.5.7 Point-Source Propagation Runs

The Mittlegrund was outfitted with calibrated IR point source targets on booms extending outboard from either side of the ship, Figure 9. The temperatures of these two targets were set to emulate the point-source signature of low-flying anti-ship cruise missiles. Infrared measurements were collected on these sources as the Mittlegrund increased and decreased range along Track F (Figure 2.) Detection range of the Mittlegrund was observed as a function of refraction conditions in the marine boundary layer, which is largely affected by air-sea temperature difference, ASTD, as summarized in Table 4.

Figure 9: IR Image of Mittlegrund Showing IR Sources.

Table 4: Detection Limit of Point Source vs. ASTD/Refraction Mode.

Date	Start time	End time	Type of run	**Detection limit exhaust**	ASTD (K) Pier avg	ASTD (K) FFI Buoy avg	ASTD (K) Pier @ MaxDet	ASTD (K) FFI Boje @ Max Det
11.09.2011	15:14:00	15:45:00	out-/inbound	**31 km**	3,6	4,1	3,7	4,1
12.09.2011	6:26:52	6:35:29	outbound	**19 km**	-1,3	-0,3	-1,6	-0,3
"	12:14:00	12:45:00	outbound	**19 km**	0,7	1,24	1	1,4
14.09.2011	15:41:43	15:56:49	outbound	**19 km**	2,4	-	2,25	-
"	20:00:15	20:13:11	outbound	**19 km**	-0,6	-	-0,7	-
15.09.2011	12:48:04	13:27:57	outbound	**19,5 km**	0,6	-	1	-
"	15:33:36	16:11:14	outbound	**19,5 km**	-0,2	-	0	-
16.09.2011	14:19:11	15:03:46	outbound	**21 km**	0	-	1,3	-
19.09.2011	02:18:21	02:59:19	outbound	**16,5 km**	-4,8	-3,3	-5	-3,3
"	03:53:36	04:38:04	inbound	**16 km**	-5	-3,6	-5,1	-3,5
"	04:51:30	05:35:23	outbound	**15 km**	-5,2	-3,8	-5,3	-3,8
"	06:23:45	07:01:08	inbound	**15 km**	-5,4	-3,5	-5,5	-3,7
"	08:51:00	09:47:02	out-/inbound	**16 km**	-3,6	-0,7	-3	-0,8
20.09.2011	07:43:36	08:03:29	outbound	**19 km**	-2,6	-1,1	-2,4	-1
"	08:12:44	08:54:18	inbound	**18,5 km**	-2,3	-0,6	-2,4	-1
"	09:18:41	10:21:26	outbound	**25 km**	-1,6	0,4	-1,1	0,8
	UTC	UTC			MET Station IOSB		MET Station IOSB	

Lastly, atmospheric turbulence and scintillation measurements were made, using the shore lights installed on the opposing shore of the bay at Bookniseck. The primary parameter for this effect is C_n^2; the higher the value the more turbulence. Like refraction, this phenomenon is driven by ASTD. During the SQUIRREL trial, the ASTD varied from -4 to +4.5 deg C, resulting in a good variation of C_n^2, from 4×10^{-17} to 1×10^{-14}, or a factor of ~ 250. This is illustrated in Figure 10.

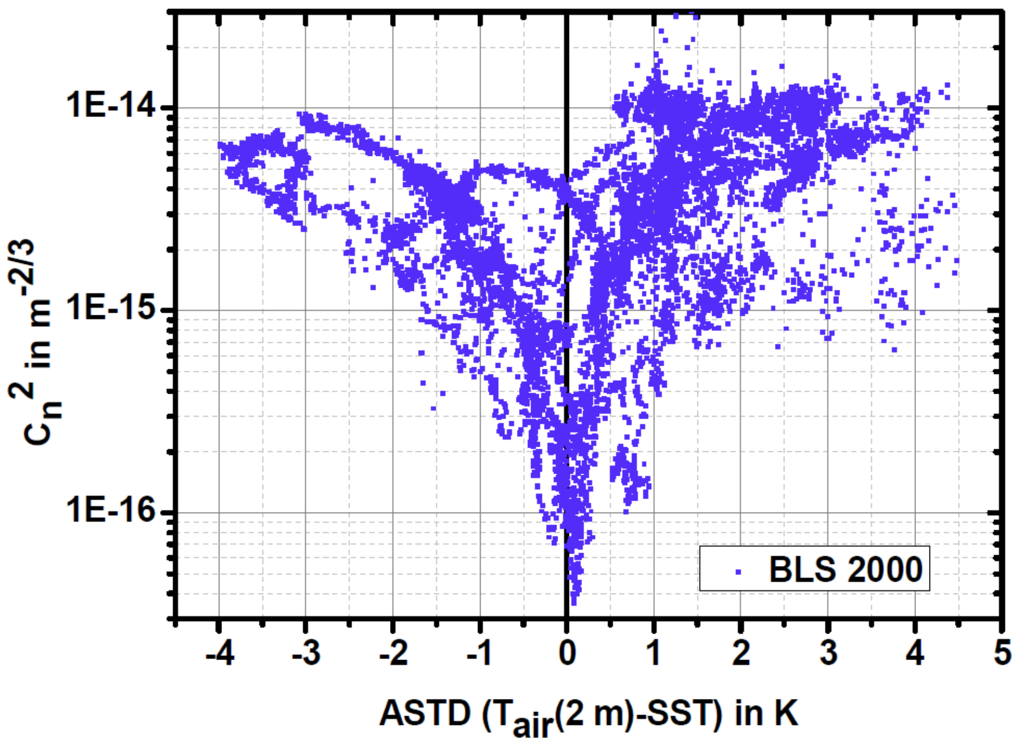


Figure 10: C_n^2 vs. Air-Sea Temperature Difference (ASTD)

6.0 SUMMARY

SET-144 was successful in that many countries participated in the Task Group and those participating Nations expended resources because they received added value over and above what each country could accomplish by itself. SET-144 advanced the state-of-the-art and knowledge-base in all six areas of research in the TOR. The major/tangible accomplishment was the planning, execution and analysis of the SQUIRREL trial.

Radiometric IR measurements were made on many types of targets:

- A 77 m research ship,
- Small marine targets (a RHIB, speedboat and combat swimmer),
- IR ship decoys, and
- A pair of small calibrated sources that simulated the signature of an anti-ship cruise missile.

The unique aspect of this experiment is it tested the effectiveness of an IR ship signature reduction system. The results of the trial were conclusive that the signature management system not only reduced signature, but would reduce missile acquisition range and improve the seduction effectiveness of off-board decoys. All of the participating countries combined their results into a comprehensive database, which is available to benefit NATO navies. The resources required to conduct such a state-of-the-art trial (ship modifications, ship transit from Canada to Germany, ~3.5 man-years of effort, 100 decoys, helicopter flight-hours) ~ € 950 k, which is too expensive for any one country to manage on its own. Clearly, close NATO cooperation is essential.

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14. Abstract
SET-144 was successful in that many countries participated in the Task Group and those participating Nations expended resources (labor and money) because they received added value over and above what each country could accomplish by itself. SET-144 advanced the state-of-the-art and knowledge-base in all six areas of research in the TOR. The major/tangible accomplishment was the planning, execution and analysis of the SQUIRREL trial. The SQUIRREL trial conducted IR radiometric measurements on a Canadian research ship equipped with a prototype signature management system. Also several other maritime targets were measured. All SET-144 Nations participated in this trial. Every country greatly benefited from this trial, which was too resource-intensive for any one country to conduct by itself.

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